Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

222
1.9622
C3T222
LIBRARY
RECEIVED
MAR ...

EFFECTS OF
GRADING STRIP-MINED LANDS
ON THE EARLY SURVIVAL AND GROWTH OF PLANTED TREES

BY

G. A. LIMSTROM

FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE

CENTRAL STATES
FOREST EXPERIMENT STATION
Columbus 15, Ohio
PHILIP A. BRIEGLEB, DIRECTOR

TECHNICAL PAPER NO. 130

NOVEMBER 1952

This report is from the

DIVISION OF FOREST MANAGEMENT

Arthur G. Chapman, Division Chief

The author is indebted to many members of the Central States Forest Experiment Station for their contributions to this paper. Special credit is due R. W. Merz, N. F. Rogers, R. F. Finn, G. H. Deitschman, F. B. Clark, D. W. Mather, and W. T. Plass for establishing forest planting experiments, installing and maintaining soil moisture apparatus, and collecting field data; and R. N. Gaiser for the wilting coefficient determinations and mechanical analyses of bank materials. Helpful advice in preparing the manuscript from A. G. Chapman, chief of the Division of Forest Management Research, and K. G. Johnson, station editor, is gratefully acknowledged. The work of Evelyn Vukovich and Virginia Simone, secretaries, and Robert Smith, draftsman, is also appreciated.

The costs of establishing the experimental plantings, including use of the land, was borne entirely by mining companies affiliated with the Ohio Reclamation Association, the Illinois Coal Strippers Association, and the Southwestern Interstate Coal Operators Association.

CONTENTS

Page

Introduction 1
- The Problem 1
- Objectives and Limitations of the Study 2

Review of Literature 2

Methods. 5
- Forest Planting Experiments 6
- Moisture Studies. 11

Results. 13
- Forest Planting Experiments 13
- Moisture Studies. 19

Discussion 29

Summary. 32

Literature Cited 33

U.S.D.A., NAL
JUN 17 2008
CATALOGING PREP

EFFECTS OF GRADING STRIP-MINED LANDS ON THE EARLY SURVIVAL AND GROWTH OF PLANTED TREES

By

G. A. Limstrom

INTRODUCTION

THE PROBLEM

The strip-mining industry has created a new type of land surface with unique sequences of plant succession and problems relating to land use. Although the area affected by strip mining is very small in comparison with the total area of unused, submarginal land in the United States, the conspicuous position of these lands on the landscape has aroused much public interest in their development.

In the Central States Region the total area stripped for coal by 1946 was estimated at 190,000 acres (11), and the acreage stripped during the preceding decade was put at 10,000 to 15,000 acres per year. These estimates, however, do not include areas affected by strip mining in Pennsylvania and West Virginia where these operations are rather extensive, nor small areas in other states outside of the Region.

Plants can be grown on most of these new land surfaces. Natural plant succession on stripped lands in Illinois was reported by Croxton (5) as early as 1928. Since that time thousands of acres established artificially as forest or pasture show the potential value of these lands. Like soils, their productivity varies with their fertility and their physical and chemical characteristics. They are, however, not as uniform in composition over large areas as most soils, and they may vary considerably in these characteristics even on small areas.

The overburden removed in typical stripping operations for coal is usually deposited in long, roughly parallel ridges or "banks," or in huge, conical mounds. Banks and mounds vary in height from only a few feet to as much as 100 feet and in slope from almost level to as high as 75 percent. These banks when newly formed are a conspicuous mass of boulders, stones, shale, and soil, in contrast to the surrounding landscape. Because of their rough and barren appearance, most present and proposed legislation to regulate reclamation programs requires that strip-mined lands be graded to a level or gently rolling topography.

To prescribe grading or leveling as the basic requirement for reclaiming all strip-mined lands is open to question. First, the effects of grading on the growth of plants and on the proposed use of each part of a stripped area should be determined and considered. Secondly, the possible harmful effects should govern the amount of grading to prescribe. Areas to be used as athletic fields or drive-in theaters, for example, would require complete leveling; for landscape beautification grading to rolling topography may be necessary; for pastures grading may be desirable; and for timber production little or no grading may be necessary. The cost of grading is usually high and from an economic standpoint is often considered not warranted. Moreover, the rough, barren appearance of many strip-mined lands is only temporary if proper reclamation measures are used.

OBJECTS AND LIMITATIONS OF THE STUDY

During the past 6 years the Central States Forest Experiment Station has investigated the effects of grading strip-mined lands on the survival and growth of forest plantations. The object of the experiments was to obtain quantitative data on these effects and to measure some important site conditions which may account for differences in survival and growth of trees planted on graded and ungraded strip-mined lands. The purpose of this paper is to publish these results and to help practitioners determine where the harmful effects of grading may be negligible and where they may be serious. Although some of the results are based on relatively young plantations, they show trends that may be indicative. They are given here because the need for specific information on the subject is urgent.

REVIEW OF LITERATURE

Because strip mining is a young industry, few comprehensive investigations on the grading problem have been reported. Most of the available literature on the subject consists of opinions not supported by data or pertains to studies on special phases of the problem.

Poor aeration and moisture conditions are generally recognized as the chief factors accounting for the poor growth of trees on some graded strip-mined lands. They are largely the result of compaction from the weight of grading machinery and from the weight of the materials which were located above the newly formed surface before grading (fig. 1). The severity of these conditions is often gauged by such soil characteristics as volume weight (apparent specific gravity), infiltration rate, porosity, water-holding

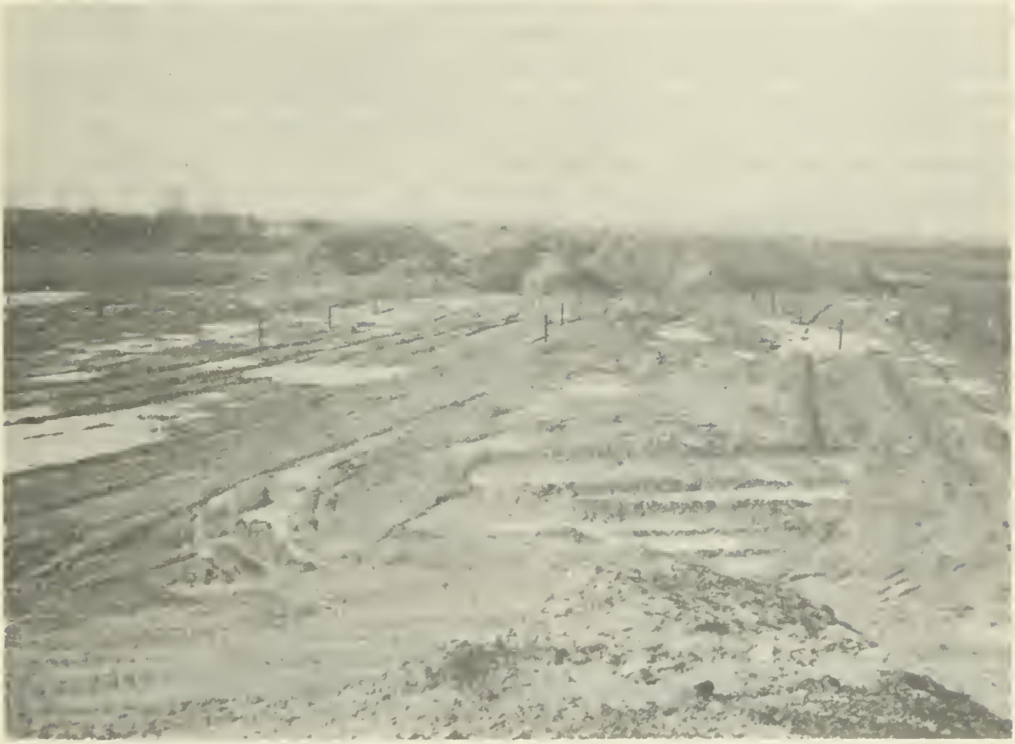


Figure 1.--Leveled strip-mined land in Barton County, Missouri, a few hours after a heavy rainfall. Compaction by grading machinery has lowered infiltration rates to such an extent that most of the water remains on the surface to be lost eventually by evaporation and runoff. Surfaces covered intermittently by standing water become cemented and "crusted over." Smoother grading to a gentle slope would reduce adverse effects of cementation but would hasten runoff. Rapid runoff into streams can be avoided by providing for catchment basins near the highwall or between bank slopes.

capacity, texture, and plasticity. On level or nearly level graded banks cementation or "crusting-over" of the bank surfaces also causes poorer aeration and moisture conditions. The amount of compaction varies with a number of factors, including the elapsed time from stripping to grading, the character of the bank materials, the weight and type of grading machinery used, the time required by the machinery to perform the grading, and the moisture content of the bank material at the time of grading.

On some graded banks in West Virginia the surfaces were reported to be compacted to depths of 18 to 24 inches (20). Stiver (18) reported greater compaction by tractors on stripped lands in Indiana when banks were wet than when dry. These results closely parallel those obtained in compaction studies of soils. Working with Davidson loam and Cecil clay, Weaver and Jamison (21) found that compaction as measured by volume weight increased with increasing moisture content and the number of passes made over the soil by the tractor tires; they also noted that the plasticity of the soil had an important effect. According to Parker and Jenny (15) Ramona loam was compacted by tractor tires to a depth of 9 inches when dry and to 24 inches when wet.

A few studies comparing infiltration rates on graded and ungraded strip-mine lands in Ohio have been reported. On one area composed chiefly of clay and shale the infiltration rate of water on an ungraded area was eight times greater than on a graded area; the rate on the ungraded area was slightly greater than on an adjacent, undisturbed old field (4). In a rather comprehensive, well-designed test made on one stripped area composed mainly of clay and limestone, Merz and Finn (3) found a much higher average infiltration rate on ungraded banks than on graded banks.

Current investigations by Grandt (7) on the agronomic aspects of strip-mine reclamation in Illinois are showing little or no harmful effects of grading on the production of forage crops. His studies, as yet incomplete and confined to banks composed mainly of shaly, loessial and glacial material, are showing little difference in the infiltration rates between banks completely graded and those partially graded. Deep-rooted legumes and the weathering of bank materials have increased the infiltration rates on graded banks. This would seem to indicate that the effects of compaction on the growth of forage crops are temporary. In addition, the available phosphorous and potassium content of bank surfaces has generally increased after grading.

Some early results of experiments reported more fully in this paper have already been published. On one strip-mine area in Illinois planted trees grew much better on the ungraded area than on the graded area (6). Limstrom and Merz (12) found the average height of trees planted on the ungraded part of a stripped area composed chiefly of clay and limestone significantly greater than on the graded part of the same area. In another test, on banks composed chiefly of sandstone, shale, and clay, no significant differences in height growth between the graded and ungraded parts of the area were obtained.

Only a few writers have mentioned the need for site evaluations in selecting uses for strip-mined lands, and few have recognized the need for different grading standards to suit each use. Too often only the use of the land before stripping or the present use of neighboring unmined land is considered with little or no regard to changes in site conditions brought about by strip mining. In Germany, however, Hartgen (8) advocated that forests be planted on stripped lands in the vicinity of Leipzig--a region where most of the land is used for farming--to increase the local timber supply and to improve recreational facilities. The need for varying grading standards has also been recognized in England; Oxenham and Mun (14) state that "In many cases levelling is unnecessary, and in others it may be impracticable, or the cost may be prohibitive. There the planting of trees for the purpose of timber production or landscaping should be considered." The great diversity of site conditions existing on strip-mined lands in Ohio and the need for recognizing these varied conditions in selecting uses for these lands has been shown (12). Kohnke (9) has pointed out that only stripped lands that are potential pasture, crop, or orchard land need be graded.

Extensive stripping for minerals in England began some time before 1900. As a result, a few old plantations exist where growth on graded and ungraded banks can be compared. On an area near East Park, Wolverhampton, Whyte and Sisam (22) have observed that the half of a 46-acre tract left ungraded and planted to trees was more attractive 50 years after planting than the half which had been leveled and planted to the same species at the same time.

METHODS

The problem was attacked using two general methods of experimentation: first, by establishing a number of experimental plantings to compare survival and growth of a variety of species on graded and ungraded strip-mine lands; second, by comparing moisture conditions and other site factors which may account for differences in the development of forest plantations on these sites.

FOREST PLANTING EXPERIMENTS

Four experimental plantings were made, two in Ohio, one in Illinois, and one in Kansas. Those in Ohio were established in 1946, while those in Illinois and Kansas were planted in 1947. Although the field layout differed slightly in each case, all were so designed that results could be tested by analysis of variance. For convenience, each experimental area has been designated by number.

Experimental Area No. 1 was located in Harrison County, Ohio, on stripped lands resulting from the mining of No. 8, Pittsburgh, coal. This area was subdivided into two parts. One part, selected at random, was left undisturbed in the form of a series of ridges formed by the stripping operation; the other part was graded to an almost flat, gently sloping topography. Each part was then subdivided into three blocks or replications and in each block four species were planted in randomly assigned quarter-acre plots. In each plot 225 trees of one species only were planted (table 1).

As noted in table 2, the banks on the graded and ungraded parts were composed of about 50 and 55 percent stone, respectively; this material, 2 mm. in diameter or larger, consisted largely of limestone and clay shale. The "soil" fraction (particles less than 2 mm.) was composed chiefly of silt and clay of high plasticity. When holes were dug with spade or mattock, the material loosened was cloddy and soil particles adhered to the stones. The ridges on the ungraded part ran east and west with an average relief of 30 feet and slope of 60 percent. At the time of planting the graded part was barren. The ungraded area had sparse vegetation covering about 10 percent of the surface and consisting mainly of red clover (Trifolium pratense L.), sweet clover (Melilotus spp.), wild carrot (Daucus carota L.), common plantain (Plantago major L.), dandelion (Taraxacum sp.), elderberry (Sambucus canadensis L.), and ragweed (Ambrosia sp.).

Experimental Area No. 2 was located in Columbiana County, Ohio, on lands strip mined for No. 7, Upper Freeport, coal. The species planted and design of the experiment were the same as for Area No. 1. Ridges on the ungraded part ran east and west with an average relief of 15 feet and slope of 45 percent (fig. 2A). The graded area sloped gently southward (fig. 2B).

The texture of the banks on Area No. 2 was much coarser than on Area No. 1 (table 2). The average proportion of stone--chiefly sandstone and hard shale--was 57 and 68 percent as compared with 50 and 55 percent on the graded and ungraded parts, respectively, on Area No. 1. For the soil fraction there was three times as much sand and less than one-half as much clay on the surfaces of Area No. 2 as on the surfaces of Area No. 1. Moreover, the

Table 1.--Location, site descriptions, and species planted on four experimental areas established to test effects of grading strip-mined lands on survival and growth

Variables	Experimental area number			
	1	2	3	4
Location	Harrison County, Ohio	Columbiana County, Ohio	Saline County, Illinois	Crawford County, Kansas
Composition	Limestone, clay, clay-shale	Sandstone, shale, clay	Sandstone, limestone, shale, clay, sand	Limestone, sandstone, shale, clay
Acidity range, pH	6.8 - 8.0	6.5 - 7.0	3.8 - 7.2	3.0 - 7.2
Wilting coefficients[1]				
Graded area	10.5	7.5	-	[3] 10.7
Area not graded	9.5	7.0	-	
Year stripped	1942	1944	1944	1939
Grading				
Year	1946	1946	1944	1939
Equipment	Bulldozer	Bulldozer	Dragline	Dragline
Planting				
Year	1946	1946	1947	1947
Species[2]	White ash, yellow poplar, white pine, black locust	White ash, yellow poplar, white pine, black locust	Green ash, black locust, sweet gum, loblolly pine, shortleaf pine, red cedar	Black locust, green ash, black cherry, bur oak seed, sycamore, jack pine, Virginia pine

---

[1] The wilting coefficients were determined by the following procedure: one hundred wheat plants were grown in 300-gram samples of 2 mm. bank materials in paraffined paper containers until they had developed large root systems. Then the material was covered with paraffin (just at melting temperature) and the plants were allowed to wilt permanently, as detected by partial yellowing and total collapse. At this point, the percentage of moisture (based on oven-dry weights) was determined to obtain the wilting coefficient.

[2] For scientific names of species planted see table 3.

[3] Composite sample from graded and ungraded areas.

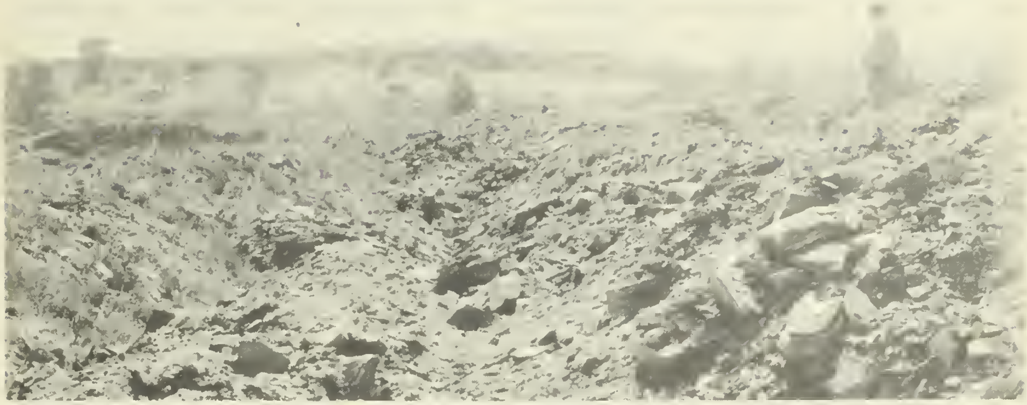
Table 2.--Mechanical analyses[1] of bank materials for three experimental planting areas on strip-mined lands by sites and depths of sample

Site and depth of sample	Experimental area											
	1				2				4			
	Harrison Co., Ohio				Columbiana Co., Ohio				Crawford Co., Kansas			
		"Soil" fraction				"Soil" fraction				"Soil" fraction		
	Stone	Sand	Silt	Clay	Stone	Sand	Silt	Clay	Stone	Sand	Silt	Clay
	Percent											
Graded 6"	49	10	43	47	56	33	44	23	43	14	49	37
12"	51	11	49	40	59	32	-	-	46	12	49	39
Not graded:												
North slopes[2]												
6"	51	11	48	41	68	30	-	-	42	15	44	41
12"	56	11	42	47	72	33	-	-	47	14	51	35
South slopes[3]												
6"	63	12	45	43	68	28	-	-	45	12	50	38
12"	57	11	54	35	65	31	-	-	53	15	48	37

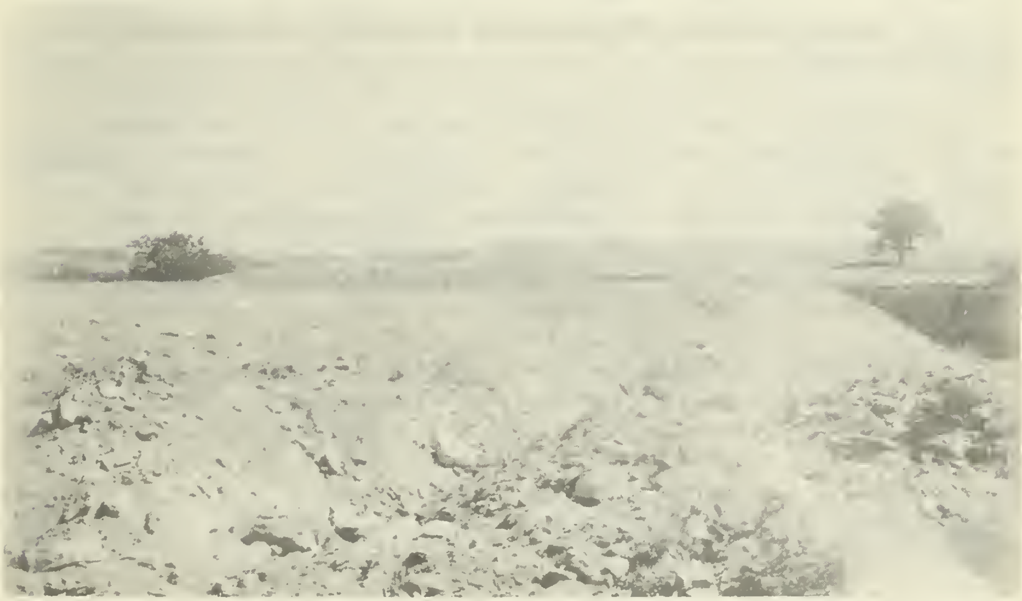
[1] Mechanical analyses of the "soil" fraction were made by the Bouyouces hydrometer method. Each analysis is based on the average of duplicate determinations made from composite samples taken from 12 random locations. The average proportion of stone was determined by sieving six or more randomly selected samples from graded and ungraded parts of each area.

[2] East slopes in Area No. 4, Kansas.

[3] West slopes in Area No. 4, Kansas.



2A



2B

Figure 2.--Experimental Area No. 2, Columbiana County, Ohio, just after planting: A, part of strip-mined area not graded; B, graded part.

consistency of these materials was much different. On the ungraded part of Area No. 2, especially, the surface materials were of loose consistency, while on Area No. 1 they were highly plastic and compact.

At the time of planting, the surface of the graded area was barren. Vegetation on the ungraded area was sparse, covering only about 10 percent of the area. Principal plants were ragweeds (Ambrosia spp.), sorrel (Rumex acetosella L.), and dandelion (Taraxacum spp.).

Experimental Area No. 3 was located in Saline County, Illinois, on lands stripped for No. 6 coal. This experimental area consisted of two parts. One part was graded with a dragline as a part of the stripping operation; the ungraded part was located on the same area but had been stripped using a shovel. Both parts consisted of two replications each containing a row of 50 trees of each species planted (table 1).

The ridges on the ungraded part, running east and west, were rather steep and high with an average relief of 60 feet and gradient of 65 to 75 percent. The graded area sloped gently to the north. Bank materials on both parts of the area were a mass of limestone, sandstone, shale, and loess. Stone made up about 60 percent of the mass. The "soil" was classed as a silt-loam, of loose consistency on the ungraded part and rather compact on the graded part.

Vegetation on the ungraded area was sparse, consisting mainly of Lespedeza, wild lettuce (Lactuca sp.), ragweed (Ambrosia spp.), shepherd's-purse (Capsella bursa-pastoris (L.) Medic.), goldenrod (Solidago spp.), beardgrass (Andropogon sp.), sweet clover (Melilotus spp.), and sedges (Cyperaceae). More than 75 percent of the graded area was barren; Andropogon was the principal component of its sparse vegetation.

Experimental Area No. 4 was located in Crawford County, Kansas, on lands stripped for No. 9, Mineral, coal. This experimental area consisted of three blocks, or replications. Half of each block was located on ungraded banks, while the other half was on banks which had been graded by draglines at the time of stripping. On both parts of each block 100 trees of each species were planted in tenth-acre plots (table 1).

The graded parts of the area were almost level except for a few mounds and a scattering of pot-holes which intermittently filled with water during the year. The ridges on the ungraded areas ran north and south with an average relief of 20 feet and slopes of 50 percent. Surface materials on both parts of the area contained about 46 percent stone made up chiefly of sandy, silty, and clayey shales, limestone, and sandstone (table 2). The soil fraction was composed of about 13 percent sand, 48 percent silt, and 39 percent clay. It was classified as friable on the ungraded parts and compact to plastic on the graded parts.

Although only 25 percent of the entire area was covered with vegetation at the time of planting, a wide variety of herbs, shrubs, and trees were noted. The herbaceous cover included aster (*Aster* spp.), bindweed (*Convolvulus* sp.), bracted plantain (*Plantago aristata* Michx.), broomsedge (*Andropogon virginicus* L.), buttonweed (*Spermacoce glabra* Michx.), dewberry (*Rubus* sp.), dock (*Rumex* sp.), evening-primrose (*Oenothera* sp.), goldenrod (*Solidago* spp.), pokeweed (*Phytolacca americana* L.), ragweed (*Ambrosia* spp.), rattlebox (*Crotalaria* sp.), sage (*Salvia* sp.), sunflower (*Helianthus* sp.), sweet clover (*Melilotus alba* Desr.), wild lettuce (*Lactuca* sp.), wood-sorrel (*Oxalis* sp.), and triple-awned grass (*Aristida* sp.). The shrubs included blackberry (*Rubus* sp.), sumac (*Rhus* sp.), and wild rose (*Rosa* sp.). The trees included green ash (*Fraxinus pennsylvanica*, var. *lanceolata* Borkh. Sarg.), cottonwood (*Populus deltoides* Marsh.), elm (*Ulmus* sp.), and wild plum (*Prunus americana* Marsh.).

MOISTURE STUDIES

In order to find some of the causes of differences in development of trees planted on graded and ungraded strip-mined lands, a comprehensive study of moisture conditions was conducted during the summer of 1948. In these studies, located on Experimental Planting Areas No. 1, 2, and 4, in Ohio and Kansas, plaster of Paris blocks with lead-in wires attached were imbedded at a number of places and depths on the three areas. Moisture conditions, as expressed by the electrical resistance of the blocks, were determined using a modified Wheatstone bridge (*2*). Because only moisture trends were desired, the apparatus used was not calibrated for each area; this was considered necessary only if exact measures of available water were needed. The main object of this study, however, was to compare the critical moisture conditions on the two different sites on each area.

Readings of 60,000 ohms or higher at 70° F. were regarded as critical and in the range of permanent wilting of most plants. Resistance readings of 400 ohms or less were considered as indicative of saturated conditions--"too wet" for good plant growth; readings of 400 or less are well within the range indicating water held in excess of the so-called field capacity of soils. Readings taken at temperatures above or below 70° F. were corrected in the standard manner (*2*).

On the graded part of each experimental area, 12 plaster of Paris blocks were imbedded at depths of 6 inches and 12 inches at randomly chosen locations. On the ungraded parts of Experimental Areas No. 1 and 2 in Ohio an equal number of blocks were placed at both depths in the middle of south-facing slopes, and in the middle of north-facing slopes at randomly chosen locations. On Experimental Area No. 4 in Kansas the same number of blocks were placed in the middle of east-facing and west-facing slopes. A total of 72 blocks were placed on each experimental area; 12 at each of two depths on the graded part, and 12 at each of two depths on each of the two major exposures on the ungraded parts.

In addition to these installations, blocks were placed at 6-inch and 12-inch depths at three locations near the tops of ridges and near the bottoms between ridges. Readings from these locations were not used to compare moisture conditions on the graded and ungraded parts of the area, but were taken primarily to compare moisture conditions on the two extreme sites on ungraded banks.

In placing the blocks, holes were dug to the desired depth with a mattock, the blocks saturated in distilled water and placed in a horizontal position at the proper depth. In order to obtain good contact, fine material to a thickness of about one-half inch was placed around each block. The rest of the excavated material was then packed firmly into the hole. The entire process roughly simulates tree planting by hoe or mattock methods as the material was repacked in the hole to about the same degree of compaction as when planting trees.

The blocks were installed at all locations in August 1947. Readings were taken about five times per week at Experimental Area No. 4 in Kansas, from May 24 to September 17, 1948. On the Ohio areas readings were taken about three times per week from May 12 to September 7. There were 5,688 individual block readings taken on the Kansas area during the entire season and 2,448 readings at each of the two experimental areas in Ohio.

Gauges to record precipitation were installed at each of the three experimental areas. This made it possible to correlate changes in moisture conditions of block materials with the distribution and intensity of precipitation. Soil temperatures were taken at various depths each time block readings were taken so corrections in the moisture readings could be made for temperatures deviating from 70° F. (2).

RESULTS

All experiments reported in this study were so designed that some approved method of statistical analysis could be used in evaluating results and in testing significance. The results consist mainly in survival and growth records of trees planted on graded and ungraded strip-mined lands 3 to 5 years after planting. In addition, one season's study of moisture conditions on these sites is reported.

FOREST PLANTING EXPERIMENTS

The results obtained from the tree planting experiments varied considerably by species, geographical locations, and bank characteristics. The differences in survival and growth between trees planted on graded and ungraded banks were tested for significance by analysis of variance (17).

Survival

In general, the survival to date has been better on the ungraded parts of the experimental areas than on the graded parts (table 3). In 18 out of 24 cases, the average survival on the ungraded parts was superior and in 1 case the difference was 55 percent. On the 6 cases out of the 24 where survival was higher on the graded parts, all differences were less than 6 percent. On the graded areas, moreover, the mortality continued at a relatively high rate after the first growing season. The over-all survival at the end of the first year, for example, was 68.7 and 74.3 percent on the graded and ungraded parts, respectively. At the end of the third year, however, the over-all survival on the graded parts dropped to 55.1 percent in contrast to 69.3 percent on the ungraded part. This represents an average loss during the second and third years of only 5.0 percent on the ungraded parts and 13.6 percent on the graded parts.

Separate statistical analyses of survival data were made for each of the four experimental areas. This was necessary because of varying numbers of species and replications involved. Because results varied from one area to another, they are reported separately.

On Experimental Area No. 1, Harrison County, Ohio, survival generally was good for both graded and ungraded parts (table 3). Statistically, no significant differences in over-all survival were found. However, for yellow poplar--a species with rather exacting site requirements for good survival and growth--the average survival on the graded part was only 14 percent, in contrast to 47 percent

Table 3.--Comparative survival and total height of trees planted on graded and ungraded strip-mined lands at four experimental areas in Ohio, Illinois, and Kansas

Area number, location, and age of plantation	Species planted		Survival		Total height	
	Common name	Scientific name	Graded	Not graded	Graded	Not graded
			- - Percent - -		- - Feet - -	
No. 1, Harrison County, Ohio (5 yrs. old)	Black locust (1-0)[1]	*Robinia pseudo-acacia* L.	96	99	17.3	19.5
	White ash (2-0)	*Fraxinus americana* L.	94	91	2.5	4.3
	Yellow poplar (1-0)	*Liriodendron tulipifera* L.	14	47	0.6	1.6
	White pine (3-0)	*Pinus strobus* L.	70	77	1.1	1.4
No. 2, Columbiana County, Ohio (5 yrs. old)	Black locust (1-0)	*Robinia pseudo-acacia* L.	97	100	16.8	16.9
	White ash (2-0)	*Fraxinus americana* L.	95	93	3.0	3.7
	Yellow poplar (1-0)	*Liriodendron tulipifera* L.	75	70	2.0	2.5
	White pine (3-0)	*Pinus strobus* L.	92	91	2.1	2.4
No. 3, Saline County, Illinois (3 yrs. old)	Green ash (1-0)	*Fraxinus pennsylvanica* var. *lanceolata* (Borkh.) Sarg.	87	86	1.3	1.7
	Black locust (1-0)	*Robinia pseudo-acacia* L.	97	92	8.5	8.5
	Sweet gum (1-0)	*Liquidambar styraciflua* L.	52	74	0.8	2.2
	Loblolly pine (1-0)	*Pinus taeda* L.	18	73	1.0	2.9
	Eastern red cedar (1-0)	*Juniperus virginiana* L.	77	79	1.0	1.2
	Shortleaf pine (1-0)	*Pinus echinata* Mill.	21	52	0.6	1.7
No. 4, Crawford County, Kansas (4 yrs. old)	Jack pine (2-0)	*Pinus banksiana* Lamb.	8	25	2.6	2.6
	Eastern red cedar (1-0)	*Juniperus virginiana* L.	51	53	2.2	2.7
	Black locust (1-0)	*Robinia pseudo-acacia* L.	72	93	10.7	13.9
	Green ash (1-0)	*Fraxinus pennsylvanica* var. *lanceolata* (Borkh.) Sarg.	45	59	2.2	2.8
	Black cherry (1-0)	*Prunus serotina* Ehrh.	20	64	1.7	2.1
	Virginia pine (1-0)	*Pinus virginiana* Mill.	20	51	2.2	3.4
	Pitch pine (1-0)	*Pinus rigida* Mill.	18	43	1.6	1.8
	Bur oak seed	*Quercus macrocarpa* Michx.	25	30	0.4	1.5
	[2]Sycamore (1-0)	*Platanus occidentalis* L.	16	54	1.6	2.7
	[2]Shortleaf pine (1-0)	*Pinus echinata* Mill.	34	48	0.9	1.6

---

[1] The first number is the number of years in nursery seedbed; the second number is the number of years in the nursery transplant bed.

[2] 3 years old.

on the ungraded part. Note that the survival of white pine on the area, though satisfactory, was at least 15 percent lower than the survival of black locust and white ash.

Survival on Experimental Area No. 2, Columbiana County, Ohio, was better than on the other areas (table 3). No significant differences in survival between the graded and ungraded parts were found. Note especially the good results with yellow poplar and white pine in contrast to poor and fair survival for these species on Area No. 1.

On Experimental Area No. 3, Saline County, Illinois, significant differences in survival were obtained for species planted on the graded and ungraded parts. Mortality of shortleaf pine, loblolly pine, and sweet gum was especially high on the graded banks, but the losses sustained by green ash, black locust, and eastern red cedar are not considered serious.

For nearly all species the survival on the graded part of Experimental Area No. 4, Crawford County, Kansas, was much lower than on the ungraded part. Statistically, the differences were highly significant. Except for black locust the survival on these sites cannot be considered good; survival on the ungraded part was barely acceptable and plantings on the graded part failed. From the standpoint of initial survival, only red cedar, black locust, green ash, black cherry, sycamore, and perhaps bur oak, of the 10 species tested, are suitable for planting on stripped lands of this character in the locality.

Growth

Differences in height growth of trees planted on the graded and ungraded parts of the experimental areas were not as pronounced as the differences in survival for some species, but ungraded banks showed consistently better growth (fig. 3). In all cases the average total height of trees on the ungraded banks was equal to or superior to that obtained on the graded banks (table 3). On two of the four areas these differences in height were highly significant, and on one of the areas they were significant. In 20 out of 24 cases these differences have increased as the age of the plantation increased.

On Experimental Area No. 1, Harrison County, Ohio, highly significant differences in average heights were obtained. The growth of yellow poplar on the graded areas was especially poor; tops of many of the trees died each year and, as a result, the average heights, largely sprouts, were no greater after 5 years than at the time they were planted. White ash appears more promising than yellow poplar on graded banks of this composition, but even its average height at the end of the fifth year was

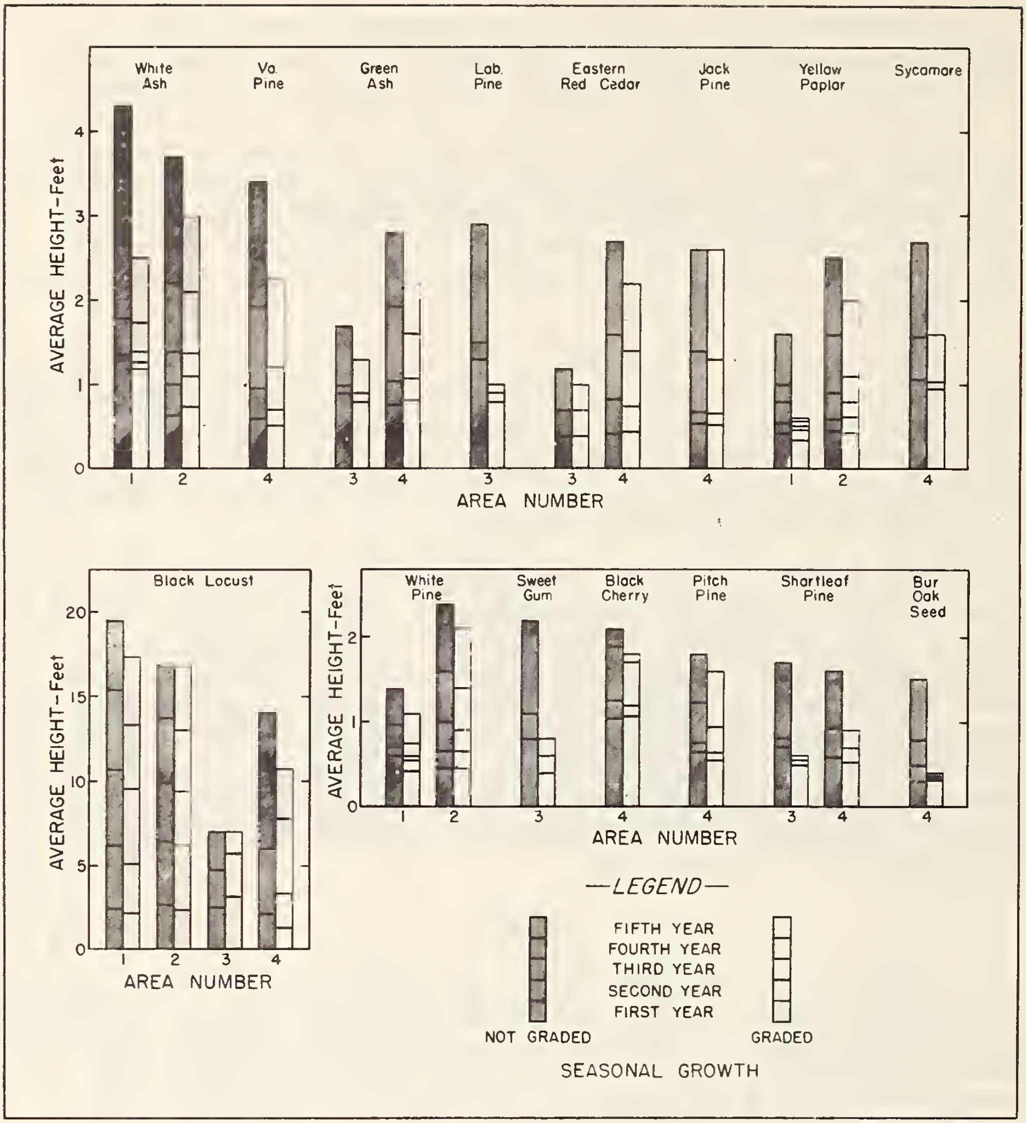


Figure 3.--Comparative seasonal growth and total height of trees planted on graded and ungraded strip-mined lands for four experimental areas in Ohio, Illinois, and Kansas. The first season's growth includes the height of the seedlings at the time of planting. Area No. 1 is located in Harrison County, Ohio, No. 2 in Columbiana County, Ohio, No. 3 in Saline County, Illinois, and No. 4 in Crawford County, Kansas.

scarcely more than half its average height on the ungraded banks. White pine grew poorly on both graded and ungraded parts of the area; calcareous banks, especially those composed mainly of heavy, plastic clay, are not suitable sites for this species. For black locust, a species noted for its rapid juvenile growth, the difference of slightly more than 2 feet may not be important.

The graded part of this experimental area has developed into two remarkably different site conditions: the "cuts," marking the location of the tops of ridges before grading where considerable compaction has occurred, and the "fills," located in the areas occupied by bottoms and lower slopes before grading. Growth has been seriously retarded on the "cut" sections of the graded banks (fig. 4) but not in the "fills." Since the differences in growth have been fully reported in an earlier publication (12), the detailed results are not repeated.

On Experimental Area No. 2, Columbiana County, Ohio, measurements after 5 years indicate no significant differences in average total heights of the trees planted on the graded and ungraded parts of the area. Although the average heights of the trees on the ungraded part are slightly higher than those on the graded part, individual plot averages were not consistent enough to make these differences statistically significant. Note that white pine and yellow poplar grew better on this area than on Experimental Area No. 1 (fig. 4). The growth of black locust and white ash, on the other hand, was slightly less than on Area No. 1. However, growth of all species planted on the area was good.

On Experimental Area No. 3, Saline County, Illinois, 3 years after establishment, growth of trees on the ungraded part was significantly better than on the graded part. The differences for sweet gum, loblolly pine, and shortleaf pine were particularly high. The development of black locust on the area is especially interesting; during the first two growing seasons growth was more rapid on the graded part, but in the third season, growth on the ungraded part had accelerated (fig. 3) to such an extent that average heights at the end of the third season for both parts were identical.

On Experimental Area No. 4, Crawford County, Kansas, highly significant differences were obtained for the average height of trees on the graded and ungraded parts 4 years after planting. The growth of black locust, Virginia pine, shortleaf pine, bur oak, and sycamore was especially better on the ungraded area. The development of green ash, eastern red cedar, and black cherry on the graded area was almost as good as on the ungraded.

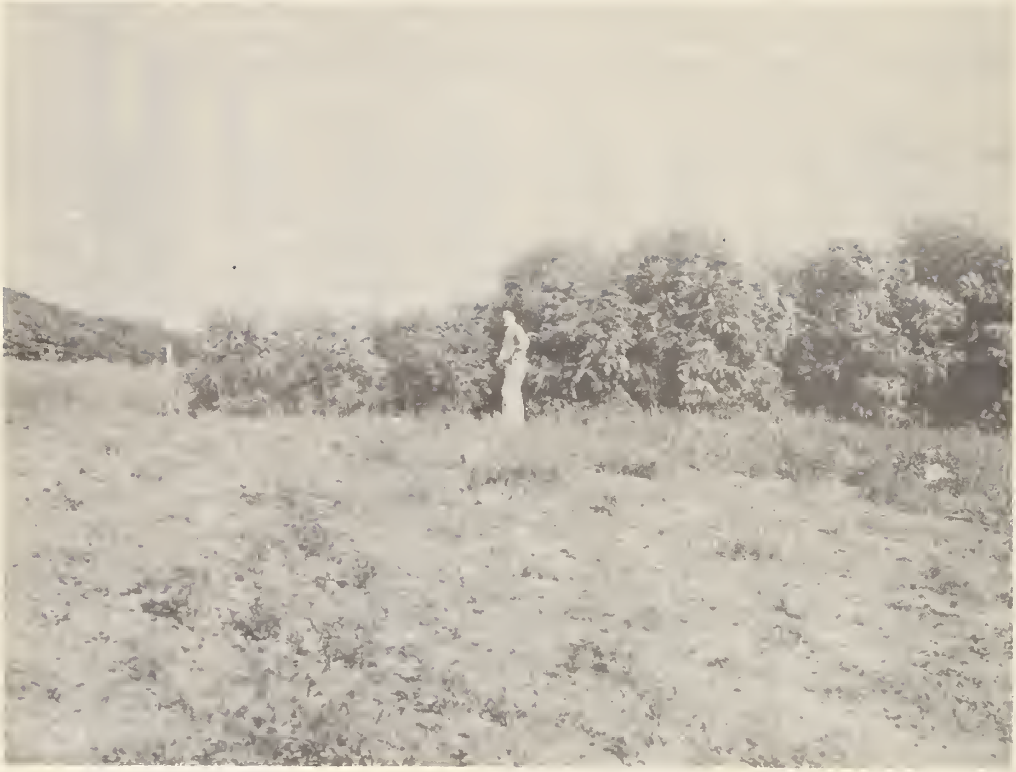


Figure 4.--Variations in growth of black locust 3 years after planting on graded strip-mined lands at Experimental Area No. 1, Harrison County, Ohio. Area to left of center is the "cut" section which was subjected to considerable compaction; area to right of center is the "fill" section which was not subjected to much compaction. Trees on both sections are from the same lot of planting stock and were planted at the same time. How long this compaction will effect tree growth is not yet known.

MOISTURE STUDIES

All of the 10,578 readings taken during the summer of 1948 to compare moisture conditions on graded and ungraded parts of the three experimental areas were sorted into three classes: (1) "too dry," which include those readings above 60,000 ohms at 70° F. and definitely in the wilting range of most plants; (2) "too wet," which includes readings of 400 ohms or less and definitely in the saturation range of soils; and (3) intermediate readings which have been classed as satisfactory or "good." These results are summarized in table 4. Comparisons between the various sites on each area were made by Chi-square tests (17). The analyses, based on the number of readings indicating "good" moisture conditions, differed somewhat among the various sites and depths sampled.

Between graded and ungraded banks: With the exception of the 12-inch depths on Areas No. 2 and 4, all analyses showed highly significant differences in good moisture conditions between graded and ungraded banks. The weighted average number of readings indicating "good" moisture conditions on the three experimental areas was 713 on the graded and 815 on the ungraded banks.

Between graded banks and north slopes of ungraded banks: On Experimental Area No. 1, with relatively high relief, highly significant differences between graded banks and north slopes of ungraded banks were obtained for both depths sampled. On Experimental Area No. 2, with relatively low relief, no significant difference was found.

Between graded banks and south slopes of ungraded banks: With the exception of the 12-inch depth in Area No. 2, highly significant differences in moisture conditions were obtained.

Between graded banks and east slopes of ungraded banks: On Area No. 4, highly significant differences in moisture conditions were obtained for the 6-inch depth. For the 12-inch depth no significant differences were obtained. (East slopes do not occur in Areas No. 1 and 2.)

Between graded banks and west slopes of ungraded banks: On Area No. 4, highly significant differences in moisture conditions were obtained for the 6-inch depth. For the 12-inch depth there were no significant differences.

Between north and south slopes of ungraded banks: With the exception of the 6-inch depth on Area No. 2, the differences in moisture conditions between north and south slopes were found to be highly significant.

Table 4.--A comparison of moisture conditions for graded and ungraded sites on three strip-mined areas, 1948

Area No. and location	Depth sampled	Poor moisture conditions			Good moisture conditions	Total
		Too wet	Too dry	Total		
	Inches	- - - - Number of determinations- - - -				
No. 1, Harrison County, Ohio						
Graded	6	33	111	144	264	408
	12	61	82	143	265	408
Not graded:						
North slopes	6	26	32	58	350	408
	12	25	19	44	364	408
South slopes	6	28	61	89	319	408
	12	68	23	91	317	408
No. 2, Columbiana County, Ohio						
Graded	6	1	39	40	368	408
	12	3	31	34	374	408
Not graded:						
North slopes	6	4	21	25	383	408
	12	36	12	48	360	408
South slopes	6	5	11	16	392	408
	12	11	11	22	386	408
No. 4, Crawford County, Kansas						
Graded	6	93	422	515	433	948
	12	333	179	512	436	948
Not graded:						
East slopes	6	56	313	369	579	948
	12	220	260	480	468	948
West slopes	6	67	383	450	498	948
	12	223	252	475	473	948

Between east and west slopes of ungraded banks: On Area No. 4, where these exposures occur, highly significant differences in moisture conditions were obtained at the 6-inch depth. There were no significant differences for the 12-inch depth.

In general, better moisture conditions prevailed on the north and east slopes of the ungraded banks than on the south and west slopes and on the graded banks. The differences between graded and ungraded banks were more highly significant as texture of bank materials became heavier; Area No. 1 had the highest proportion of clay, Area No. 2 was very coarse-textured, and Area No. 4 intermediate.

These analyses, based on the number of readings classed as "good," "too dry," and "too wet," may not, however, give an exact comparison of moisture conditions which prevailed on the three areas for the season; the total number of days with critical moisture conditions is perhaps more important for this comparison. The average number of days of poor moisture conditions for the entire season is shown graphically in figure 5. The procedure followed in computing data shown in the figure can best be explained by an example. If a block remained "too wet" from May 22 to May 26 and from June 5 to June 10, the total number of days "too wet" was recorded as 5 plus 6 or 11 days; if "too dry" from July 10 to 12, July 24 to 28, and August 30 to September 17, the total number of days "too dry" was recorded as 3 plus 5 plus 19 or 27 days. The number of days "too wet" and "too dry" were obtained in this manner for the 12 blocks at each depth and site, and from these totals the means shown in the figures were determined.

Note in figure 5 that the poorest moisture conditions for the season occurred on Area No. 4 in Kansas. Moisture conditions were not particularly serious on Area No. 1 in Ohio and were considered good on Area No. 2 in Ohio. Of special interest also is the rather consistent increase in number of days of poor moisture conditions from north and east slopes, south and west slopes, to the graded parts of each area. For the 6-inch depth, most of the poor moisture conditions are due to drought, while for the 12-inch depth a high proportion are due to saturation; this is especially true for the graded part of Area No. 4.

Periodic changes in moisture conditions during the season reveal some interesting and perhaps significant relationships with the distribution and amount of precipitation (figs. 6, 7, and 8). Values shown at each date of measurement on the graphs indicate the average number of consecutive days with poor moisture conditions for that date. For example, if one block at a given date had been classified as "too dry" or "too wet" for the three preceding days, another for 6 days, etc., the average number for the 12 blocks was then calculated and entered on the graph for that

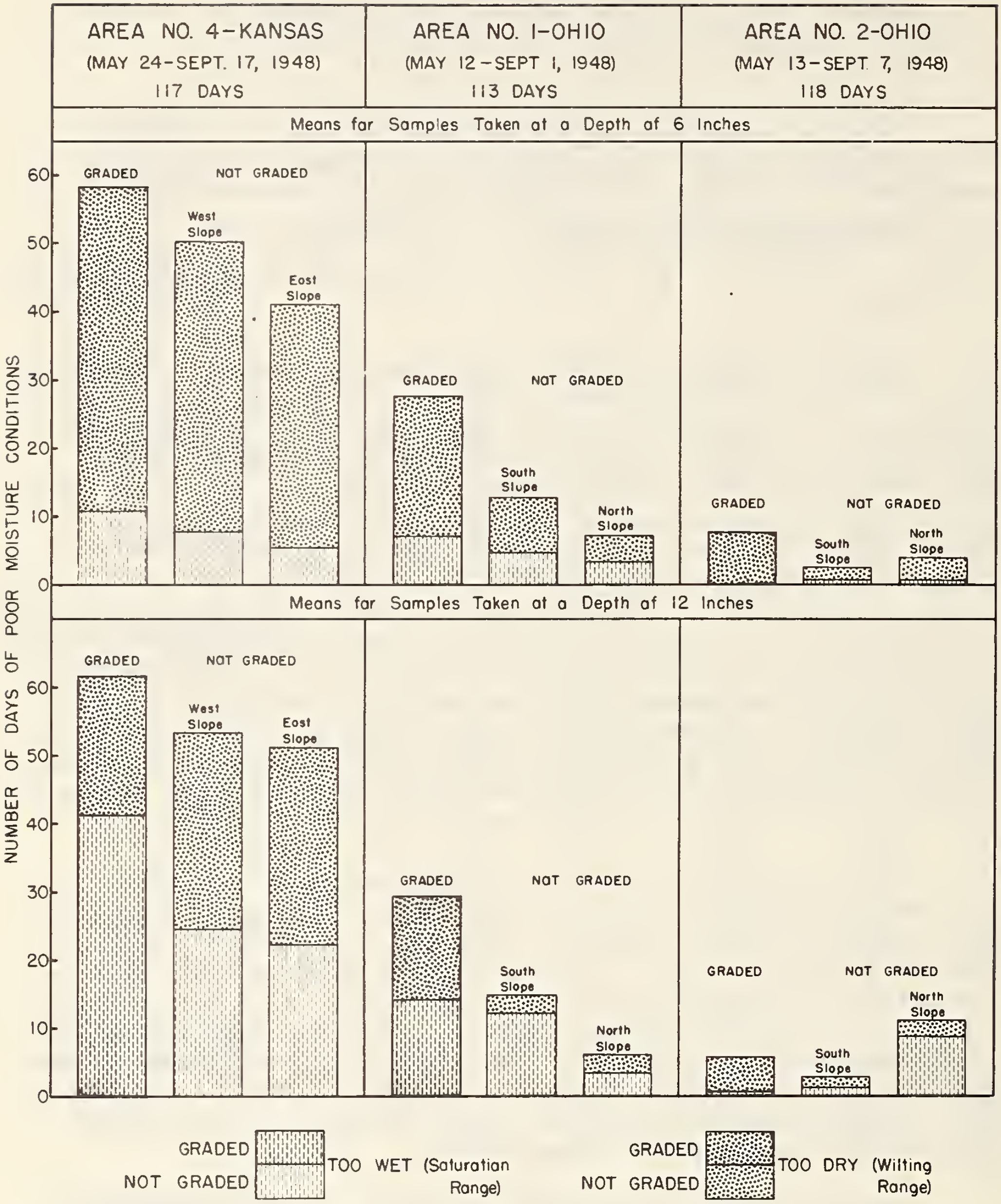


Figure 5.--Average number of days with poor moisture conditions on graded and ungraded parts of strip-mined lands for three experimental areas, 1948.

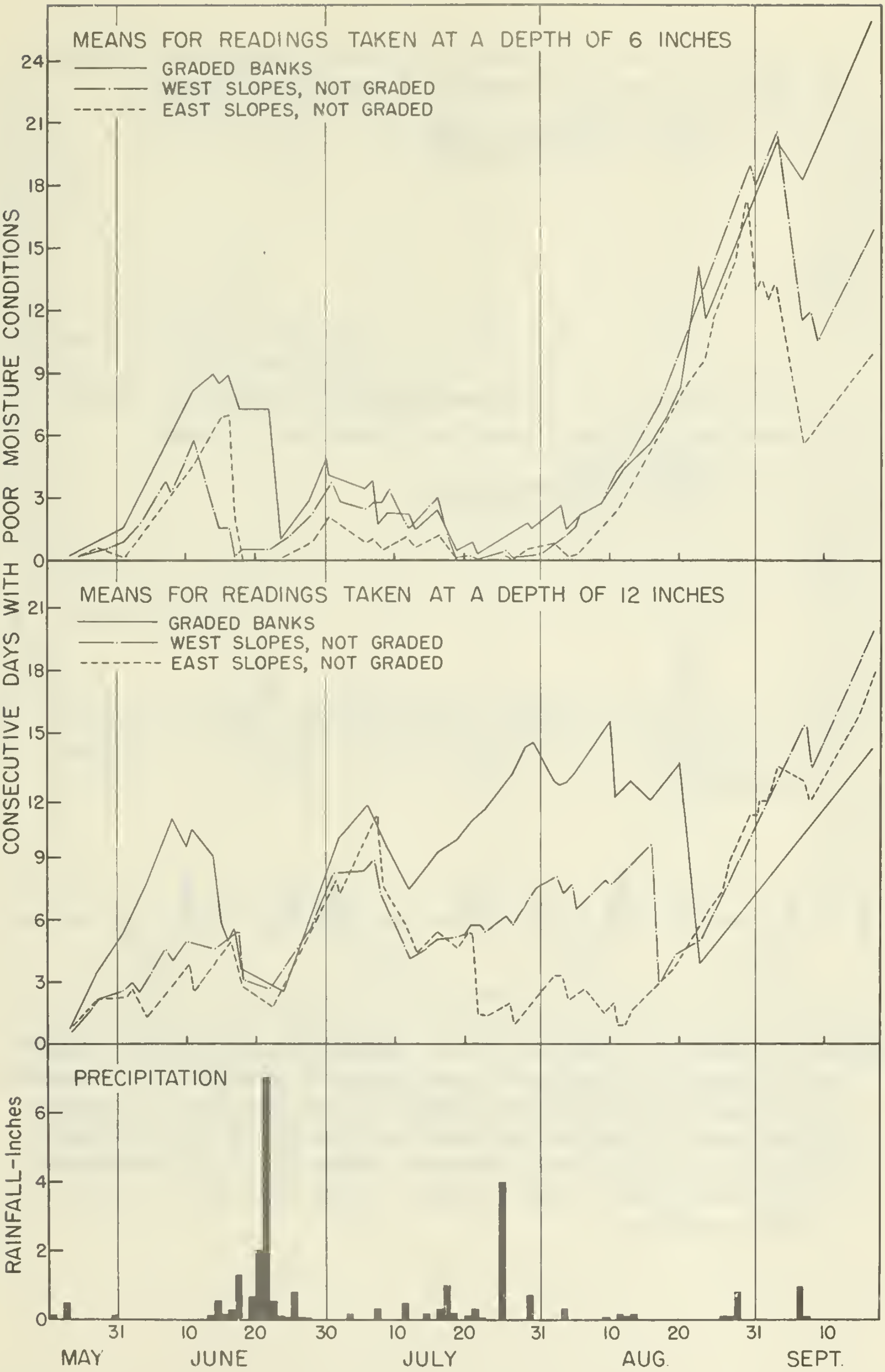


Figure 6.--Relation between daily precipitation and the number of consecutive days with poor moisture conditions on graded and ungraded strip-mined lands for two sampling depths at Experimental Area No. 4, Kansas, for the summer season of 1948. Basis: Readings of 72 plaster of Paris blocks taken five times each week; a total of 5,688 readings.

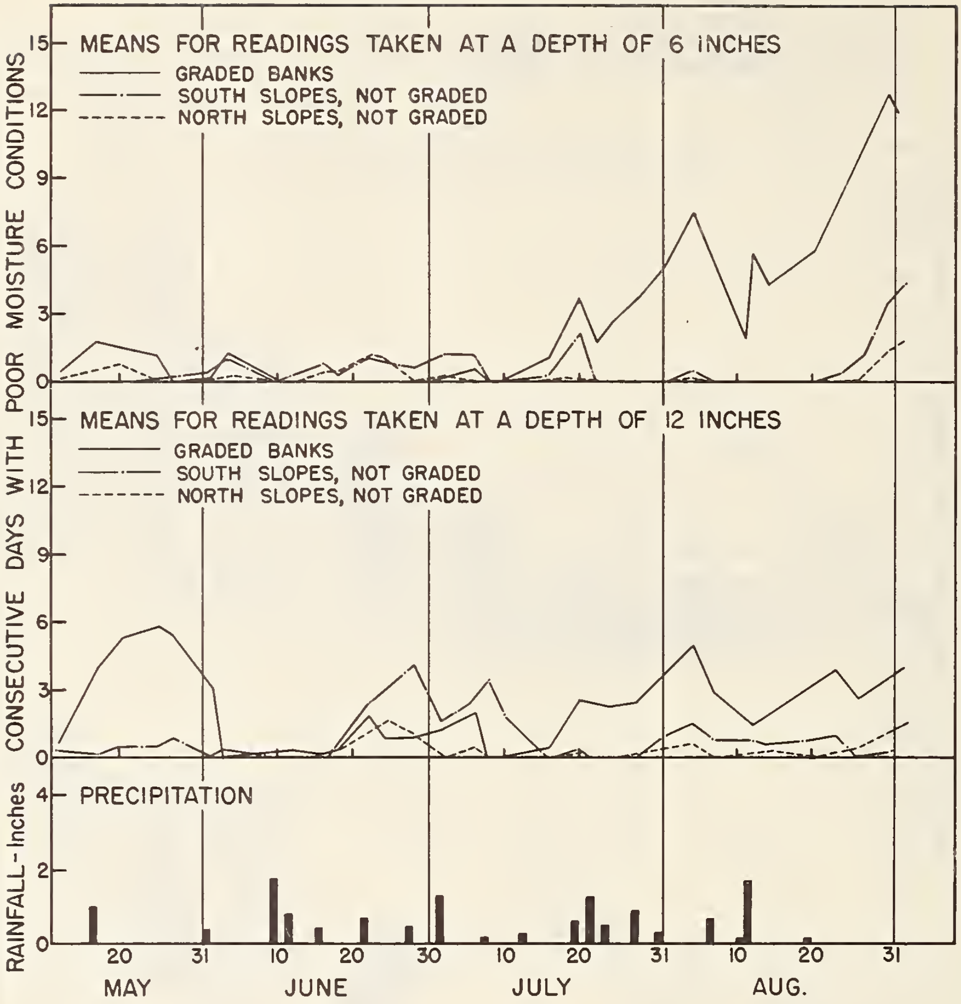


Figure 7.--Relation between daily precipitation and the number of consecutive days with poor moisture conditions on graded and ungraded strip-mined lands for two sampling depths at Experimental Area No. 1, Harrison County, Ohio, for the summer season of 1948. Basis: Readings of 72 plaster of Paris blocks taken two to three times each week; a total of 2,448 readings.

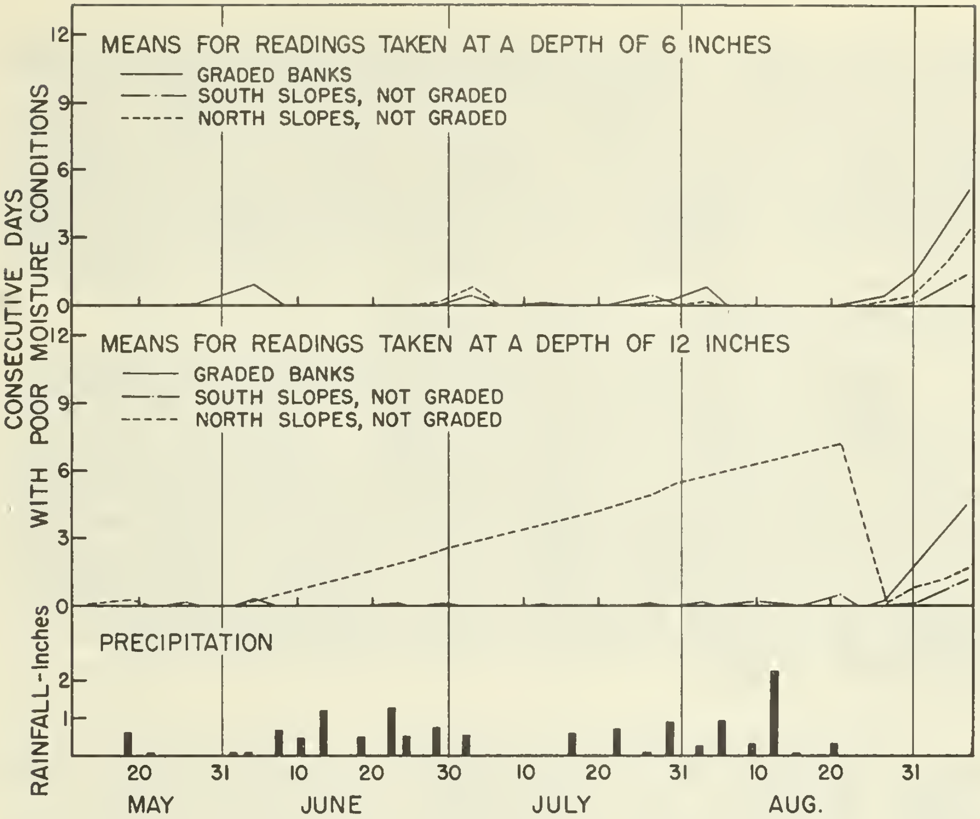


Figure 8.--Relation between daily precipitation and the number of consecutive days with poor moisture conditions on graded and ungraded strip-mined lands for two sampling depths at Experimental Area No. 2, Columbiana County, Ohio, for the summer season of 1948. Basis: Readings of 72 plaster of Paris blocks taken two to three times each week; a total of 2,448 readings.

date. At Area No. 4, Kansas, drought conditions existed from May 13 to June 15; from June 16 to July 31 there was too much rain, but from August 1 to September 17 only a little rain was recorded. At Area No. 1, Ohio, rainfall conditions were good until August 12; after that date, however, less than four-tenths of an inch of rain was recorded to September 1, the last day measurements were taken. Except for the relatively short period from August 22 to September 7 when less than two-tenths of an inch of rain fell, moisture conditions at Area No. 2, Ohio, were good.

For the 6-inch depth, moisture conditions on the graded part of Area No. 4 were much poorer than on the ungraded part for the period of drought from May 13 to June 15 (fig. 6). During the period of abundant rainfall, moisture conditions on all sites remained about the same. During the late summer drought moisture conditions on graded and ungraded parts continued to get worse at about the same rate until August 29. On that date 0.71 inches of rain fell. An additional 0.95 inches of rainfall on September 7 improved the moisture conditions on the ungraded banks; the graded banks continued to dry, however, with no perceptible benefit from this rain.

During the dry period from May 13 to June 15 the trends in moisture conditions at the 12-inch depth on Area No. 4 were similar to those recorded for the 6-inch depth. During the period of abundant rainfall, however, moisture conditions at the 12-inch depth were considerably poorer (too wet) on the graded part than on either slope of the ungraded banks. At the end of this period, note the sudden drop in the number of consecutive days with poor moisture conditions for the graded banks from August 20 to August 23; this marks the relatively short transition period from conditions "too wet" to the period when drought conditions begin. From August 23 the number of consecutive days of poor moisture conditions (largely too dry) continues to rise sharply even after the dates with 0.71 and 0.95 inches of rainfall. The long period of saturation at the 12-inch depth on the graded part did, however, have some good effect during the early stages of the drought period; it accounts for a slightly lower number of consecutive days with poor moisture conditions at the 12-inch depth on the graded part during this period.

For Area No. 1, Harrison County, Ohio, good moisture conditions prevailed on both graded and ungraded banks during the first part of the growing season (fig. 7). After the middle of July, however, there was a definite trend towards poorer conditions on the graded part for both depths sampled. On Area No. 2, Columbiana County, the amount and distribution of rainfall was exceptionally good for bank materials of coarse texture until about the middle of August (fig. 8). The slightly higher values for the 12-inch depth on the north slope are perhaps due to "quirks in sampling" which sometimes occur. Readings from a single block indicated continual saturation from June 2 to August 21. After August 21 only 0.2 inches of rainfall was recorded until the end of the study period, September 7. Because the drought was short, these banks did not dry as much as those on the other experimental areas. However, the graded parts tended to have poorer moisture conditions during periods of drought just as they did on the other experimental areas.

The results of the special study of moisture conditions as influenced by aspect and topographic position on ungraded strip-mined lands are summarized in table 5. Based on the number of readings classed as "too wet" and "too dry," the Chi-square analyses (17) showed a close relationship between the number of significant differences and precipitation. On Areas No. 1 and 2 in Ohio, where the distribution and amount of rain for the season was considered good, very few significant differences in moisture conditions among the various aspects and topographic positions were obtained. At Area No. 4, in Kansas, which was subjected to alternate periods of drought and saturation during the season, many significant differences in moisture conditions were found.

At Area No. 1 no significant differences between the upper parts of north and south slopes were found. In the comparison of topographic positions, the differences in dry conditions between bottoms and the tops of south-facing slopes were highly significant only at the 12-inch depth. The differences in dry conditions between lower and upper parts of north-facing slopes for the 12-inch depth--and in saturated conditions between lower and upper parts of south-facing slopes for the 12-inch depth--are just barely significant.

At Area No. 2 only one comparison was significantly different--dry conditions between lower and upper parts of south-facing slopes for the 12-inch depth.

At Area No. 4 most of the differences were found to be significant or highly significant. A few exceptions, however, should be noted: As expected, conditions on the lower parts of east and west slopes are remarkably similar. For the 6-inch depth, no significant differences in dry conditions between the upper parts of east and west slopes were obtained. The differences for the 12-inch depth between upper and lower parts of east slopes were not significant.

Table 5.--A comparison of moisture conditions on ungraded strip-mined lands between aspects and topographic positions, 1948

Area No. and location	Depth sampled	Poor moisture conditions: Too wet	Poor moisture conditions: Too dry	Poor moisture conditions: Total	Good moisture conditions	Total
	Inches	Number of determinations				
No. 1, Harrison County, Ohio						
Near tops of north slopes	6	2	15	17	51	68
	12	3	13	16	52	68
Near tops of south slopes	6	1	15	16	52	68
	12	8	16	24	44	68
Bottoms between slopes	6	4	7	11	57	68
	12	1	5	6	62	68
No. 2, Columbiana County, Ohio						
Near tops of north slopes	6	1	6	7	61	68
	12	0	5	5	63	68
Near tops of south slopes	6	0	4	4	64	68
	12	0	7	7	61	68
Bottoms between slopes	6	1	2	3	65	68
	12	0	1	1	67	68
No. 4, Crawford County, Kansas						
West slopes:						
Near tops	6	9	69	78	80	158
	12	16	60	76	82	158
Near bottoms	6	37	36	73	85	158
	12	66	22	88	70	158
East slopes:						
Near tops	6	20	75	95	63	158
	12	63	16	79	79	158
Near bottoms	6	36	37	73	85	158
	12	65	22	87	71	158

DISCUSSION

The results of these experiments show definite harmful effects of grading strip-mined lands on the early development of planted trees. The extent of these effects varies mainly with the texture and plasticity of bank materials, climatic conditions, and species planted. The principal causes of poor site conditions on graded banks are compaction of surface materials by grading machinery and cementation of the surface as a result of poor drainage. During periods of drought, graded banks are not able to use what little rain occurs. As a result, they dry at a much faster rate than ungraded banks. When there is too much rain, graded banks tend to become much more saturated and water-logged than ungraded banks.

Drought is perhaps the limiting factor for survival while for growth, saturation or water-logging no doubt has a significant harmful effect. The investigations by Schneider and Childers (16) showing an increase in apparent photosynthesis with a slight decrease in soil moisture below the field capacity, coupled with numerous reports stressing the importance of aeration on stem and root growth (3), (10), and (19) substantiate this conclusion. The poor survival and growth (table 3) on the graded banks of Experimental Area No. 4 in Kansas, where extreme fluctuations in precipitation during the summer season are common, can no doubt be attributed to alternate prolonged periods of drying and saturation (fig. 6).

Except for coarse-textured banks in localities where droughts are uncommon, the effects of grading on plantation development are largely harmful. If good plantation development is wanted, the practitioner must carefully evaluate site and climatic conditions on each parcel of strip-mined land before deciding to grade. Although texture is perhaps the more important, there is some evidence that the plasticity of the clay fraction in bank materials is also important. Original investigations of Atterberg, as reported by Baver (1), showed that only minerals with a platy or sheet-like structure exhibit plasticity when ground. Quartz and feldspar, whose crystals are made up of linked tetrahedra, are non-plastic. Others, such as kaolinite, talc, muscovite, and biotite, whose crystal lattices are built up in sheets, are plastic. The proportion of each of these minerals in the banks would therefore have an important effect on their plasticity.

A careful mechanical analysis of bank materials and a determination of their mineral content would be desirable as an index of the possible harmful effects of grading on tree development. The practitioner, however, rarely has the facilities and training necessary for these analyses. As a substitute, the following rough, field method can be used when bank conditions are moist or wet: With mattock or shovel dig holes to a depth of 10 or 12 inches and estimate the consistency of the material excavated; if soil particles cling to the shale and other stones or are "cloddy," the banks made up of this material will most likely be very compact after grading.

These experiments have shown that the harmful effects of grading strip-mined lands on tree development varies by species. Because of poorer site conditions on most graded lands, the practitioner does not have as wide a choice of species for planting on these sites. Based on data reported in this paper, the following species are listed in their order of tolerance to compacted conditions on graded strip-mined lands: black locust, green ash, white ash, eastern red cedar, sweet gum, black cherry, shortleaf pine, Virginia pine, loblolly pine, bur oak, sycamore, pitch pine, jack pine, yellow poplar, and white pine. This tolerance ranking is only tentative as many more years of observations will be necessary before a positive ranking of species adaptability to compact site conditions can be prepared.

Tree planting is often more difficult and costly on graded banks than on ungraded. Compact surfaces on graded banks make it difficult to dig holes for planting. As a result, fewer trees are planted per man-day.

A number of proposals have been made to improve compact site conditions by varying methods of mining and techniques in grading. One such proposal is to grade banks when they are dry. While this may be helpful, there are too many practical limitations. There are few periods during the year when entire banks are dry. To grade all stripped lands during these periods would be difficult or even impossible with equipment and manpower normally available for these operations.

Grading the banks in conjunction with stripping of the overburden has also been advocated. Though this procedure has definite practical advantages and may be helpful, it certainly is not a solution to the problem. Experimental Areas No. 3 and 4 were graded at the time of stripping but considerable compaction of surface materials has nevertheless occurred.

Not all effects of grading strip-mined lands are harmful. Grading makes strip-mined lands more accessible; it simplifies and in some cases lowers the cost of establishing, caring for, and harvesting many crops. Grading may improve the appearance of the landscape, especially during the first few years after stripping. It often improves these lands for pastures and is no doubt highly desirable for such uses as vineyards, orchards, and producing cultivated crops. On some areas no ill effects of grading on the survival and growth of trees have been observed.

The findings reported in this paper are based largely on plantations less than 6 years old. Will the trends indicated by these results continue as the stands get older? We can be quite certain of the comparative survival of species on the graded and ungraded banks, but comparative growth would be hard to predict. During the first 3 to 5 years (fig. 3) annual growth on the ungraded banks increased consistently over the graded banks with each additional year of age. Empirical observations on older plantations in England have indicated better development of trees planted on ungraded banks than on graded banks (22).

SUMMARY

1. The experiments reported in this paper were conducted to obtain quantitative data on the effects of grading strip-mined lands on the survival and growth of forest plantations.

2. Four experimental plantings were established on widely varying sites in Ohio, Illinois, and Kansas, to test the effects of grading on the development of a large number of species.

3. On three of these four experimental areas a comprehensive study on moisture conditions was conducted for one growing season to compare moisture conditions on graded and ungraded strip-mined lands. Graded banks were found to dry more rapidly during periods of drought than the ungraded; this was because graded banks cannot absorb what little rain occurs during periods of drought. Conversely, when there is too much rain, graded banks tend to become more saturated and water-logged than the ungraded because of lower percolation rates brought about by the compaction of surface materials.

4. Results show that the effects of grading vary with the texture of the bank materials and climatic conditions. On coarse-textured banks in areas that do not have frequent prolonged periods of drought and excessive rainfall, the differences in survival and growth on graded and ungraded banks are negligible. On banks composed mainly of sticky, plastic clay, and especially in areas with extreme variations in rainfall, survival and growth were better on the ungraded banks, the differences being highly significant. The effects also varied by species.

LITERATURE CITED

(1) Baver, L. D.
1948. Soil Physics. Ed. 2, John Wiley and Sons, New York.

(2) Bouyoucos, G. J., and Mick, A. H.
1940. An electrical resistance method for the continuous measurement of soil moisture under field conditions. Mich. State Col. Agr. Expt. Sta., Tech. Bul. 172.

(3) Boynton, D., DeVilliers, J., and Reuther, W.
1938. Are there critical oxygen concentrations for the different phases of root activity? Science n.s. 88:569-570.

(4) Chapman, A. G.
1949. Progress in stripped land regeneration research. Amer. Mining Cong. Yearbook on Coal Mine Modernization, pp. 309-315.

(5) Croxton, W. C.
1928. Revegetation of Illinois coal stripped lands. Ecology 9:155-175.

(6) Deitschman, G. H.
1950. Seedling survival and height growth on graded and ungraded strip-mined land in southern Illinois. Central States Forest Expt. Sta., Sta. Note 62.

(7) Grandt, Alten F.
1951. The potentialities of revegetating and utilizing agronomic species on strip-mined areas in Illinois. A progress report covering the fourth year of work on a cooperative investigation conducted by Ill. Univ. Agr. Expt. Sta. and Ill. Coal Strippers Assoc. (Material from this report is used by special permission of the author and the Ill. Coal Strippers Assoc.)

(8) Hartgen, V.
1942. Untersuchungen über die Entwicklung der Aufforstung im nordwestsächsischen Braunkohlengebiet unter Berücksichtigung eines Waldgürtels für Leipzig. (Investigations on the development of afforestation in the brown coal region of northwest Saxony, with special reference to a forest belt for Leipzig.) Tharandt. Forstl. Jb. 93:253-288.

(9) Kohnke, Helmut
1950. The reclamation of coal mine spoils. Adv. in Agron. II, pp. 317-349.

(10) Kramer, P. J.
1940. Causes of decreased absorption of water by plants in poorly aerated media. Amer. Jour. Bot. 27:216-220.

(11) Limstrom, G. A.
1948. Extent, character, and forestation possibilities of land stripped for coal in the Central States. Central States Forest Expt. Sta., Tech. Paper 109.

(12) ---------------, and Merz, R. W.
1949. Rehabilitation of lands stripped for coal in Ohio. Central States Forest Expt. Sta., Tech. Paper 113.

(13) Merz, R. W., and Finn, R. F.
1951. Differences in infiltration rates on graded and ungraded strip-mined lands. Central States Forest Expt. Sta., Sta. Note 65.

(14) Oxenham, J. R., and Mun, M. I.
1948. Reclamation of derelict land. Jour. of the Institution of Municipal Engineers, London 75(3):182-202.

(15) Parker, E. R., and Jenny, H.
1945. Water infiltration and related soil properties as affected by cultivation and organic fertilization. Soil Sci. 60:353-376.

(16) Schneider, G. William, and Childers, N. F.
1941. Influence of soil moisture on photosynthesis, respiration, and transpiration of apple leaves. Plant Physiol. 16:565-583.

(17) Snedecor, George W.
1946. Statistical methods. Ed. 4, The Collegiate Press, Inc., Ames, Iowa.

(18) Stiver, Edward N.
1949. Unpublished thesis: Revegetation of strip coal spoil banks of Indiana. Presented to the Faculty of the Graduate School of Purdue Univ. for the degree of Doctor of Philosophy.

(19) Tukey, H. B., and Brase, K. D.
1938. Studies of top and root growth of young apple trees in soil and peat-soil mixtures of varying moisture contents. Amer. Soc. Hort. Sci. Proc. 36:18-27.

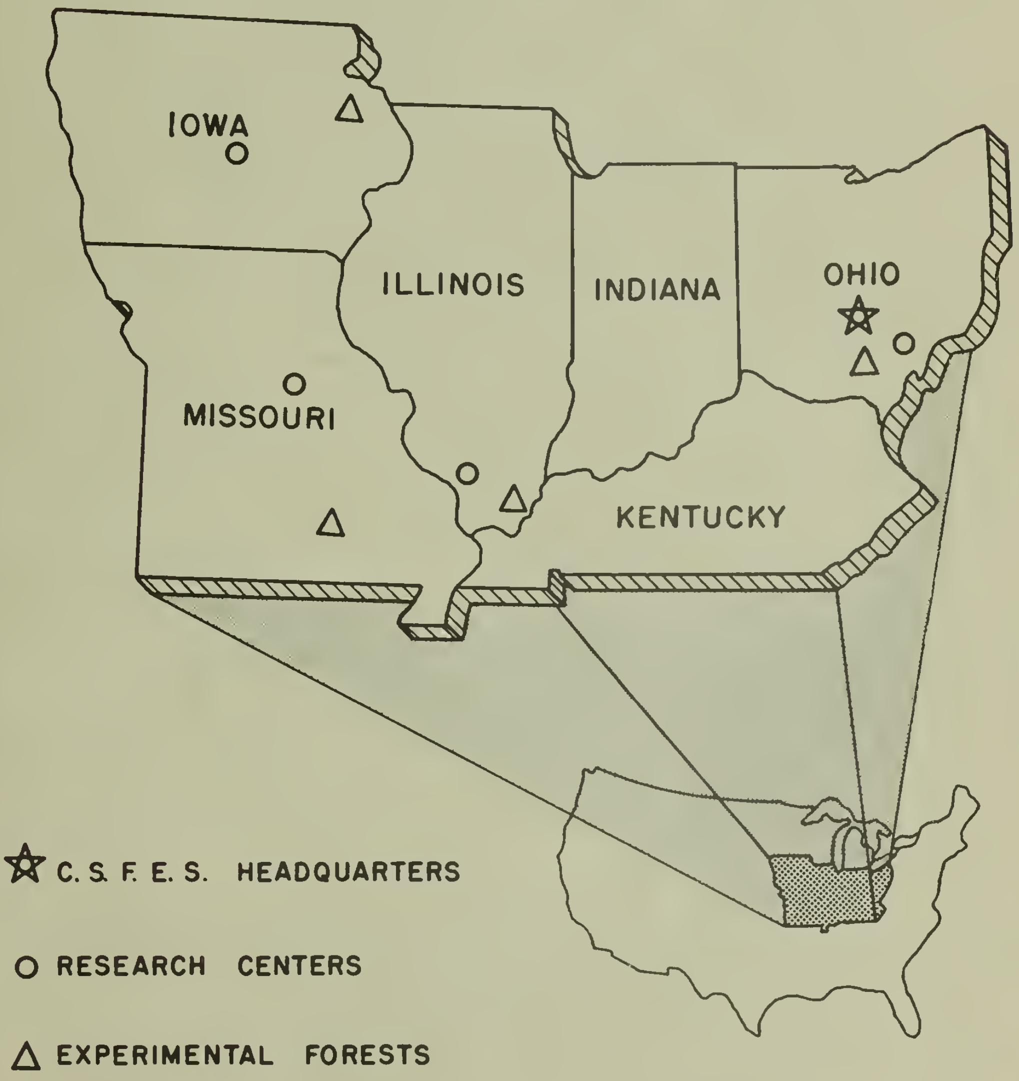
(20) Tyner, Edward H., Smith, Richard M., and Calpin, Sydney L.
1948. Reclamation of strip-mined areas in West Virginia. Amer. Soc. Agron. Jour. 40:313-323.

(21) Weaver, H. A., and Jamison, V. C.
1951. Effects of moisture on tractor tire compaction of soil. Soil Sci. 71:15-23.

(22) Whyte, R. O., and Sisam, J. W. B.
1949. The establishment of vegetation on industrial waste land. Commonwealth Agricultural Bureaux Joint Pub. 14, Oxford.

NATIONAL AGRICULTURAL LIBRARY
1022500893

TERRITORY SERVED BY THE
CENTRAL STATES FOREST EXPERIMENT STATION
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE



☆ C. S. F. E. S. HEADQUARTERS

○ RESEARCH CENTERS

△ EXPERIMENTAL FORESTS

NATIONAL AGRICULTURAL LIBRARY
1022500893